Trade and the spatial distribution of transport infrastructure*

Gabriel J. Felbermayr†
University of Hohenheim, Ifo Institute Munich, CESifo

This version: October, 2010

Abstract

This paper endogenizes the spatial distribution of infrastructure investment and transportation costs. Transportation costs between two addresses depend on cumulative infrastructure investment. In a continuous space setting with many independent countries, consumers demand domestic and foreign goods, while central planners care only about welfare of their own constituencies. The equilibrium of the game between countries features under-investment and excessive spatial variation. The distribution of infrastructure is skewed towards central regions, rationalizing the non-linear trade-impeding role of distance in empirical gravity models. French data on transportation costs and an empirical gravity model for trade between US states corroborate the theory.

JEL Codes: F11, R42, R13

Keywords: Political Economy, Economic Geography, International Trade, Infrastructure Investment, Border Effect Puzzle.

*I am grateful to seminar participants at the universities of Zürich, Kostanz, Tübingen, Giessen, TU Darmstadt, and the European University Institute for comments. Previous versions of this paper have been circulated under the title Economic Geography and the Endogenous Spatial Distribution of Transport Infrastructure Investment.

†Address: Ifo Institut for Economic Research at the University of Munich, Poschingerstraße 5, 81679 München, Germany. Tel.: +49(0)89/9224-1428. Email: felbermayr@ifo.de.
1 Introduction

Trade costs play an increasingly important role in the empirical and theoretical trade literature, in models of economic geography, or in international macroeconomics. They are responsible for a wide range of results related to the home market bias, the core-periphery pattern, or real exchange rates (see the surveys by Feenstra, 2004; Obstfeld and Rogoff, 2000; Fujita, Krugman, and Venables, 1999). Trade costs come in many guises: they comprise “all transport, border-related, and local distribution costs” (Anderson and van Wincoop, 2004). One major challenge in recent research is to account for the large empirical role of border effects that cannot be explained by trade policy.

Transport costs are usually related to geographical distance while the border effect is attributed to some lumpy cost that materializes when crossing a border. This dichotomy of variable and fixed costs enjoys empirical support, see Anderson and van Wincoop (2003). The latter authors estimate that the US-Canadian border reduces international trade relative to intranational trade by a factor of 4.7.\(^1\) Explanations for fixed border costs abound. Among other things, they are related to informational costs (Casella and Rauch, 2003), contract enforcement costs (Anderson, 2003), exchange rates (Rose and van Wincoop, 2001). Surprisingly, border effects exist also within countries, where the above explanations do not help.\(^2\) In this paper, we argue that there need not be any explicit cost related to crossing the border for a border effect to appear in empirical trade flow models. The reason is that rational planners find it optimal to underprovide infrastructure investments in geographical areas that are peripheral to their respective

---

\(^1\) Prior to Anderson and van Wincoop (2003), McCallum (1995) compares trade flows within Canada to flows between Canadian provinces and U.S. states, controlling for distance and regional GDPs. Everything else equal, crossing the border reduces trade by a factor as high as 22. For Europe, Nitsch (2000) finds that on average intranational trade is about 10 times higher than international one. Nitsch arrives at his results after controlling for cultural proximity (language), along other conventional gravity covariates. Wei (1996) constructs measures for imports of countries to themselves and compares this with imports from a statistically identical foreign country. He finds that the former magnitude is 2.5 times larger than the latter. Helliwell (1998) offers a comprehensive overview of the pre Anderson and van Wincoop state of the econometric literature. Evans (2003) decomposes cross-country price differences of traded goods into a component due to distortions and a component driven by consumer preferences. She demonstrates that the preferences effect is relatively important quantitatively. Obstfeld and Rogoff (2000) have cited this fact as a major puzzle in international macroeconomics.

legislative territories. This implies that overcoming geographical distance is more costly when a different legislative regions are involved and trade flows cross political borders. The reasoning behind this key result is the following. Each region’s social planner cares only about utility of domestic agents. However, consumers demand goods from all possible locations. Hence, investment at any location improves the utility of all consumers in the world. Since regional social planners are assumed to behave in a non-cooperative way, they fail to internalize the effect of their infrastructure investment decisions on consumers other than those residing in their political constituency. This behavior leads to global infrastructure under-investment. It also biases investment within countries towards central regions since the average domestic consumer benefits more from central than from peripheral investment. Our result is sufficiently general to survive in a number of different political economy setups and economic environments. It follows from the fundamental separation between political and economic space, the former being regional, the latter global in scope.

There are only few recent papers that study the effect of transport infrastructure on trade costs and welfare. Limao and Venables (2001) find that up to 60 percent of the cross-country variation in transport costs is due to differences in the quality and quantity of transport infrastructure. Moreover, Venables (2005) argues that infrastructure explains a larger share of spatial income inequality than sheer geography, while the latter certainly is a determinant of the former. Finally, Bröcker (1998) shows that pan-European transport infrastructure projects have important implications for spatial inequality. Those papers have in common that infrastructure is taken as exogenous and that countries (or regions) do not have a geographical extension. The present paper relaxes these assumptions.

Modeling endogenous infrastructure decisions in a spatial world is worthwhile in its own right, since it leads to interesting political issues relating to efficient provision of transport infrastructure. However, the excessive spatial variation of infrastructure investment that results from the political economy process may help towards an explanation of the border puzzle. Empirically, anecdotal and more rigorous econometric evidence both suggest that trade costs are larger whenever border regions are involved. For example, Combes and Lafourcade (2005) document a strong core-periphery pattern of real trade costs for France. This pattern cannot be explained by variation in topology alone, suggesting systematic core-periphery pattern in the quality and quantity of infrastructure investment.

The present paper is related to literature that jointly considers international and intranational aspects of trade. Courant and Deardorff (1992) emphasize the importance
of trade within-countries for trade patterns across countries. New economic geography models also discuss inter-country dynamics in the context of globalization. A recent example of such a paper is Rossi-Hansberg (2005), who studies the effects of small border costs on the regional distribution of workers within a country. He then assesses the implications of the equilibrium population distribution on intra-versus international trade flows. However, his focus is not on infrastructure investment. Transport economists have a tradition to evaluate the effects of regional transport infrastructure projects in the context of international trade; however, there does not seem much work that both endogenizes the spatial distribution of infrastructure along with its economic implications.

Formally, a close cousin of the present paper is the racetrack model of Fujita et al. (2001, ch. 6 and 17). In that model, space is continuous and organized along a circle, just as in the proposed setup. However, the two approaches differ in focus. The racetrack model endogenizes the distribution of manufacturing labor across space under conditions of increasing economies of scale. It does not say anything on the endogenous spatial distribution of the stock of transport infrastructure and how, nor on how that stock shapes transport costs. In the proposed setup, production technologies exhibit constant returns to scale, and the distribution of workers is exogenous. In turn, transport costs are endogenous. While the proposed model can be generalized to allow for increasing returns to scale and worker mobility, excluding these elements makes the model straightforward to analyze. Essentially, in the conventional economic geography setup it is worker mobility that drives regional differences, in the present framework it is the infrastructure investment decisions of central planners.

The paper contributes to the literature along three dimensions: First, while maintaining the basic iceberg trade cost assumption, we propose a plausible and tractable formulation of transportation costs as a function of cumulative infrastructure investment. This requires modeling regions (or countries) as having some spatial extension themselves. Second, governments implement their preferred infrastructure allocations across space separately for their specific spatial reach. Hence, transport costs are endogenous. Governments turn out to invest too little in border regions, therefore generating a border effect even in absence of formal and informal trade barriers. Finally, the paper

\[\text{3The racetrack model is discussed also as the ‘seamless world model’ (Krugman and Venables, 1997).}\]

\[\text{4Much of the economic geography literature (Fujita et al., 1999) and almost all new trade models do not explicitly model the spatial extension of countries. The global economy is assumed to be a collection of countries each modeled as points without spatial extension of their own.}\]
presents tentative econometric evidence based on data for US states.

The structure of the paper is as follows. Section 2 presents some stylized facts on the transportation sector and proposes a mathematical formalization of transport costs, where infrastructure investment has an important role to play. Section 3 sets up the general equilibrium environment which motivates intra- and international trade. Section 4 discusses the optimal spatial distribution of infrastructure investment in an autarkic economy and shows that the main features of the distribution do not depend on the precise nature of the political economy process. Later on, it allows for international trade (along intranational one) and shows how a Nash equilibrium for a world with many symmetric countries can be constructed. Section 5 presents tentative econometric evidence in favor of the mechanism, and section 6 concludes.

2 Stylized facts

This section shows for the case of France that the spatial distribution of transportation costs exhibits variation difficult to explain with geographical and demographic determinants. It briefly discusses established stylized facts on the provision of public transport infrastructure and how those can be used in explaining spatial patterns in infrastructure investment.

2.1 The spatial distribution of transport costs

The world is not flat. Geographical obstacles such as mountains, rivers or swamps, affect the ease at which goods and people move across space. Since the most ancient civilizations, states have invested heavily in infrastructure projects to overcome geographical distance more efficiently. While military objectives have often been looming large, interregional exchange of goods always played an important role, too. Hence, there is little doubt that—along obvious geographical factors—government actions have a bearing on the spatial distribution of infrastructure, too.

The stock of transport infrastructure investment is very difficult to measure, and there are virtually no data to carry out spatial comparisons. Hence, a more indirect approach is required. For instance, one can see to what extent geographical variables explain variation in variable transportation costs across regions and interpret the residual as shaped by the quality of transport infrastructure investment.

Reliable data on transportation costs is difficult to obtain. However, there is a recent
study by Combes and Lafourcade (2005), who provide estimates of transportation costs for 1998 across French départements. That data is particularly interesting, because the authors adopt a comprehensive perspective on transportation costs. They report the total cost incurred by transporting by standard truck a standardized container from one departemental capital to another. They take account of the cost of fuel, truck depreciation, tire use, the wage bill and accommodation costs of the truck driver(s), road tolls, taxes, and insurance costs. For the purpose of the present paper, we look at variable costs, thereby excluding expenses related to the loading and unloading of the truck.

Combes and Lafourcade use their data to calculate measures of average remoteness of regions, i.e., the average cost to reach some place from the rest of France. Not surprisingly, they document a strong core-periphery pattern. In the present context, we are more interested in the spatial gradient of transportation costs. We use the Combes-Lafourcade data to construct a proxy of the incremental trade costs per kilometer of transiting through a département. The Appendix contains the details on the construction of that proxy.

It turns out that the spatial variation in the variable cost of overcoming one unit of distance is not constant over space. Per kilometer costs of overcoming one kilometer of distance are on average 4.79 French Francs. The associated standard deviation is 2.77.

Figure 1: Population density, difficulty of territory, and variable trade costs per km in France. (Shading grows darker as respective values rise.)

Figure 1 plots the density of population (population per square kilometer), a measure of the geographical difficulty of territory (defined in the Appendix), and average variable transportation costs incurred by transiting a département (also defined in the Appendix). Not surprisingly, population density is highest in the Paris region (about 20,000 inhabi-
tants per square kilometer in Paris intra-muros, and somewhat lower in the closer Parisian neighborhood (Île de France). Regions with strong urban conglomerations, such as the Lille or Lyon regions (départements Nord and Rhône, respectively) have densities of 450. Départements in border regions have above average values, while interior départements have densities below average. Our measure of difficulty of territory is based on the difference between the highest and the lowest altitude above sea level in a département. This measure is naturally high in départements that in the Alps, the Pyrenees, or the Massif Central. It is low in coastal areas or along large rivers (e.g., the Loire valley).

The rightmost panel of 1 shows transportation costs per kilometer. There is no strong observed association of transportation costs to geographical or demographic features. However, costs tend to be low when the territory is easy or the population of density is high. Transportation costs are lowest in the Paris or Lyon region. However, they are also low in the strongly populated North-West.

Table 1 reports the results of simple regressions that attempt to explain the pattern of transportation costs across space. Column (1) shows that the geographical difficulty of territory explains about 15 percent of the variance in transportation costs. Column (2) adds population and land surface to the regression. This effectively accounts for the role of population density. As expected, an increase in density reduces the variable transportation costs. Moreover, the R-squared of the regression surges to 54 percent.

Columns (3) to (6) include different measures of the overall remoteness of geographical units. Depending on the variable included, the R-squared of the regression increases to up to 60 percent. Moreover, regardless of the exact measure of remoteness, transiting more remote regions is significantly more costly, holding geographical and demographic factors constant. Ceteris paribus, changing the remoteness measure from its lowest to its highest sample realization increases transport costs by 3.4 to 18.4 percent.

2.2 On the determination of transport costs

Next, we turn to some important stylized facts on the provision of transport services. Unfortunately, data is more easily available for the US than for Europe. Hence, the following draws on US data. When available, European data tends to look comparable.

Fact 1: Infrastructure investment explains transport costs well. Limao and Venables (2001) run regression analyses on several data sets to explain measured trade costs as a
Table 1: Different remoteness measures and average transit costs

| Dep. var.: Ln variable transport costs per km for transits through a département |
|----------------------------------|----------------------------------|
| (1) Ln distance (km) to Paris  | (2) Ln GTC to Paris | (3) ln GTC remoteness | (4) ln GTC remoteness | (5) ln weighted GTC remoteness |
| Remoteness                      | 0.175*** (0.064) | 0.491*** (0.014) | 0.485* (0.025) | 0.983** (0.043) |
| Ln population                  | -0.040*** (0.012) | -0.034*** (0.012) | -0.027*** (0.011) | -0.042*** (0.013) | -0.040*** (0.012) |
| Ln area (km²)                  | 0.094*** (0.011) | 0.084*** (0.011) | 0.065*** (0.012) | 0.092*** (0.011) | 0.088*** (0.011) |
| Ln geography                   | 0.410*** (0.130) | 0.210** (0.077) | 0.096 (0.099) | 0.105 (0.092) | 0.040 (0.090) | 0.029 (0.095) |
| Constant                       | 1.590*** (0.22) | 1.363*** (0.22) | 1.253*** (0.20) | 1.119*** (0.18) | 0.939** (0.46) | 1.295*** (0.21) |

N 94 94 94 94 94 94
adj. R² 0.15 0.54 0.57 0.60 0.54 0.56
F − stat. 10.06 44.45 44.65 61.82 35.42 41.06
RMSE 0.097 0.072 0.069 0.067 0.072 0.070

Robust standard errors in parentheses, ***p < 0.01, **p < 0.05, *p < 0.1.

function of infrastructure investment and other determinants. They find that about 60% of the variation in transportation costs can be explained by cross-country differences in the quantity and quality of infrastructure. They conclude that transport infrastructure is quantitatively more important in explaining transportation costs than sheer geography.7

**Fact 2: Intracontinental trade flows are mostly land-borne.** Since the border puzzle appears in trade within the European Union, NAFTA, or Japan, it is natural to take a brief look at the relative prevalence of intercontinental transport modes. Table 2 reports data for within NAFTA trade in 2001. It appears that two thirds of the value of total trade flows between NAFTA member states is transacted by means of trucks. Total land-borne traffic amounts to about 83 percent of the total value of trade. Hence, while the share of air-borne traffic is certainly increasing, it is not prevalent. Not surprisingly, in terms of quantities, water-borne traffic appears relatively important, reflecting the low unit-value of bulky goods transported by that mode. 8

---

7See also Venables (2005).

8Combes and Lafourcade (2006) note that, “in Europe, around 72% of trade volumes are shipped through the road network (against around 15% for rail, 8% for pipers and 5% for rivers)” (p. 324), which roughly corresponds to the North American pattern.
Table 2: US trade with NAFTA countries by mode

<table>
<thead>
<tr>
<th>Mode</th>
<th>Value</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck</td>
<td>67.3</td>
<td>36.6</td>
</tr>
<tr>
<td>Rail</td>
<td>15.8</td>
<td>19.7</td>
</tr>
<tr>
<td>Air</td>
<td>6.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Water</td>
<td>5.0</td>
<td>43.4</td>
</tr>
<tr>
<td>Other</td>
<td>5.6</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Pipeline transport excluded.
Source: Bureau of Transportation Statistics.

Fact 3: The public input into the provision of transportation services is important. According to the Bureau of Economic Analysis, in the US, public gross investment plus government consumption spending on transportation goods amount to about 9.4 percent of total government spending (across all levels of government) or 1.8 percent of GDP in 2004. Private gross fixed investment in transport equipment (this excludes cars used for private use) is 1.3 percent of GDP. Hence, albeit the fact that private and public investments into transportation goods differ dramatically in terms of their nature, they are both quantitatively significant and comparable in size. Whether publicly provided transport infrastructure is financed through taxes or through user fees such as the road tolls does not matter for the present argument as long as planners have discretion on where to invest toll receipts; see below. Data collected by the Bureau of Transport Statistics indicates that toll revenue finances only a small fraction of total public transport infrastructure spending in the US.

Fact 4: Regional governments influence interregional infrastructure projects substantially. All levels of government contribute towards spending on transport infrastructure and equipment. However, in the US, spending falls predominantly on the local or state level. Table 1 shows that state and local government command about 99 percent of total spending on highways and about 3 percent on transit and railroad projects. Federal involvement is higher for air and water transportation, so that the lower levels of government account for about 86 percent of total spending on infrastructure. These data are only indicative; the federal government influences local and state infrastructure decisions indirectly, e.g., through sales of federal land.

\[\text{NIPA tables 1.15 and 3.155.}\]
In Europe, the allocation of infrastructure spending on different levels of government is usually less skewed than in the US. However, in Germany, all interregional highways are planned, financed and maintained by state governments. In France, the interregional network of highways is managed centrally, but even in this case, regional entities have considerable influence over total infrastructure spending. Local governments are involved in the planning of interregional infrastructure projects in all larger OECD countries.

Table 3: US infrastructure spending on different levels of government

<table>
<thead>
<tr>
<th>USD bn, 2004</th>
<th>Federal</th>
<th>Local/State</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highways</td>
<td>1.6</td>
<td>153.0</td>
<td>154.6</td>
</tr>
<tr>
<td>Transit and Railroad</td>
<td>0.5</td>
<td>14.0</td>
<td>14.5</td>
</tr>
<tr>
<td>Air</td>
<td>17.3</td>
<td>9.0</td>
<td>26.3</td>
</tr>
<tr>
<td>Water</td>
<td>10.3</td>
<td>3.2</td>
<td>13.5</td>
</tr>
<tr>
<td>All</td>
<td>29.7</td>
<td>179.2</td>
<td>208.9</td>
</tr>
</tbody>
</table>

Source: BEA-NIPA Table 3.1505

3 Modeling transportation costs

Economic geography models, pioneered amongst others by Krugman (1991), bring together monopolistic competition with Samuelson’s (1952) iceberg trade costs assumption.\(^{10}\) The iceberg assumption has proved convenient, because it makes the introduction of a specific transportation sector redundant: during transportation, a distance-dependent share of the output shipped from the location of production gets lost, i.e. melts away. The implicit transportation sector production function uses the good being transported as the only input. Formally, assume that economic space \(S\) is unidimensional and continuous (e.g., the real line, or the circumference of a circle). For two arbitrary addresses \(x\) and \(z\) in \(S\), a Krugman-type transportation costs specification would be

\[
T(x, z) = e^{a|x - z|} \geq 1, \tag{1}
\]

where the coefficient \(a > 0\) is the iceberg decay parameter. \(T(x, z)\) models the cost of delivering a good over the distance \(|x - z|\) as an \textit{ad-valorem} tax equivalent, where the

\(^{10}\)Note that much of the new trade theory literature that discusses trade in differentiated goods under increasing returns to scale and monopolistic competition uses an essentially discrete formalization of trade costs. Associated empirical papers using the gravity equation do, however, resort to Krugman’s specification. For a model trade in continuous space see Krugman and Venables (1997).
tax income is lost in transit. In order to receive one unit of the good at \( x \), \( T(x, z) \) units of that good have to leave the factory at \( z \). A share \( 1 - T(x, z)^{-1} \) of the good ‘melts’ in transport; the share \( T(x, z)^{-1} \) arrives at \( x \) when one unit of the good is shipped at \( z \).

The iceberg formulation amounts to introducing a shadow transport sector which uses the share \( 1 - T(x, z)^{-1} \) of a good to be shipped from \( z \) to \( x \) as an input. The transport service is produced at the location of the producer (\( z \)), using the same input mix than the good to be shipped. Given the continuous space nature of our setup, one could more generally posit that transportation services are produced in some sub-interval in \([x, z] \). In the specific economic environment proposed below, these differences do not matter, as f.o.b. prices any any location are independent of demand for the variety produced at those locations.

McCann (2005) argues that (1) has the following properties, which are at least partly counterfactual. First, the delivered price of a good transported from a producer to a consumer over some distance is convex with respect to distance. Second, the specification disregards fixed costs associated to the costs, which tend to be important relative to total transportation costs, in particular for sea- and air-borne traffic. Third, freight cost ratios are independent of the quantity shipped.

In the present paper, transportation costs need not be monotonic in distance, as they reflect the endogeneous spatial distribution of infrastructure. Strict convexity of transportation costs results only in the limiting case where infrastructure is distributed uniformly across space. Moreover, the present paper is mainly concerned with intra-continental trade, which is primarily land-born (see table 2). Hence, both for the sake of simplicity and to keep in line with the literature, we stick to the iceberg assumption.

In this paper, transportation costs are modelled as a function of cumulative infrastructure investment. Public infrastructure investment refers to the process of investing some resource at specific locations \( s \in S \) with the aim of reducing transportation costs.\(^{11}\) We model the effectively available stock of infrastructure over some interval \([x, z] \in S \) as a constant elasticity of substitution aggregator function

\[
I(x, z) = \left[ \int_x^z i(s)^{1-\delta} ds \right]^{\frac{1}{1-\delta}}, \delta > 1, x \leq z, \quad (2)
\]

where \( \delta > 1 \) is a constant technological parameter (which will have a precise economic interpretation later). \( I(x, z) \) increases in distance. That formulation has the natural

\(^{11}\)Since the model proposed is static, we use the term infrastructure investment and stock of infrastructure interchangeably.
implication that spreading a constant investment budget \( B \) over increasing distance \( z - x \) lowers the available stock of \( I(x, z) \). Moreover, for (2) to converge, we require \( i(s) > 0 \) for all \( s \in [x, z] \).

Transportation costs and infrastructure are linked as follows:

\[
T(x, z) = \exp \left[ \frac{1}{\delta - 1} I(x, z)^{1-\delta} \right], \delta > 1, x \leq z, \tag{3}
\]

In (3) the address of the consumer \( x \) lies to the left of the address of producer \( (x \leq z) \). The opposite case is considered by simply putting \( T(z, x) \). The choice of functional forms (2) and (3) proofs convenient as the problem of optimally allocating \( i(s) \) over space resembles the problem of optimally allocating consumption spending over time. Moreover, the formulation (3) has properties long discussed (but rarely modelled) by transport economists (Winston, 1985, and Gramlich, 1994).

**Lemma 1** Generalized iceberg trade costs \( T(x, z) \) have the following important properties:

(i) \( T(x, z) \geq 1 \).

(ii) \( T(x, z) = \exp \left[ a(z - x) \right] \) if \( i(s) \) is a constant \( \bar{i} \) over the interval \([x, z]\), and \( a = \bar{i}^{1-\delta} / (\delta - 1) \) (Krugman, 1991).

(iii) \( T(x, z) \) is strictly increasing in distance. It is strictly convex if the distance-induced increment to \( T_z(x, z) \) in trade costs is not outweighed by an improvement in infrastructure. That is, if \( [a(z)]^2 > i'(z) \bar{i}(z)^{-\delta} \) where \( a(z) = i(z)^{1-\delta} / (\delta - 1) \).

(iv) The marginal effect of investment on \( T(x, z) \) is negative but increasing.

(v) The (interregional) elasticity of substitution between infrastructure investment at different locations is \( 0 < 1/\delta < 1 \), so that investments at different places are imperfect substitutes. Moreover, \( T(x, z) \to \infty \) if \( i(s) = 0 \) at some \( s \in [x, z] \), so that \( i(s) \) is an essential input.

(vi) Investment smoothing property: \( i = \arg \min \left\{ q \int_x^z i(s) \, ds \big| T(x, z) \leq \bar{T} \right\} \), where \( q \) is the spatially invariant price of infrastructure investment and \( \bar{T} \) is the (exogenous) target level of iceberg transportation costs.

**Proof** See the Appendix.

Property (ii) shows that (3) is a generalization of the standard specification. In contrast to the standard case, it provides a natural way to endogenize Krugman’s iceberg
decay parameter $a$ in the simple case where infrastructure investment is not allowed to exhibit spatial variation. Property (iii) is related to (ii): iceberg transportation costs are convex in distance (as in Krugman, 1991), as long as the component of $dT(x, z)/dz$ driven by variation in infrastructure investment does not outweigh the pure distance component of $dT(x, z)/dz$ that one gets if $i(s)$ is constant at $i(z)$. The latter is captured by the term $[a(z)]^2$, which also appears when taking the second derivative of the Krugman specification $T(x, z) = \exp[a(z-x)]$. For convexity, $i'(z) \leq 0$ is a sufficient condition. Hence, in general, whether $T(x, z)$ is convex in distance depends on the spatial allocation of infrastructure investment.

Properties (v) and (vi) exploit the isomorphism between (3) and the usual representation of utility in an optimal growth model. The parameter $\delta$ measures the ease with which infrastructure investment at some address can substitute for investment at another place. The restriction $\delta > 1$ ensures that investments at different places are gross complements: investment at some address makes investment at some other place more worthwhile. Moreover, investment at each address is essential to keep $T(x, z)$ bounded. Property (vi) shows that, as long as investment costs do not vary across space, the cost-efficient way to achieve some exogenous target level of transportation costs, involves a flat spatial investment profile. The desired level of investment is then given by

$$i = \{(z-x)/[(\delta-1)\ln \bar{T}]\}.$$ Discontinuities or spikes in the spatial investment profile that are unrelated to the underlying behavior of $q_t$ (omitted here) cannot be efficient.

We do not allow for incremental transport costs incurred at address $s$ to depend on the volume of traffic transiting through $s$. Actually, in equilibrium, the contrary will hold: more traffic at $s$ will encourage the planner to invest more in infrastructure, thereby driving down the gradient of $T$. This lowers the incremental trade costs at $s$ for all units of goods that transit through $s$. One could use a measure of infrastructure investment at $s$ relative to the traffic at $s$ to model congestion. While interesting, this extension is technically difficult since the volume of transit through $s$ depends on transportation costs.

4 Endowments, firms and consumers

This section embeds the transport technology described in (3) into a specific model of intra- and international trade. The model is static and features a single factor of production, labor. The economic environment combines spatial product differentiation with

---

12 The assumption $\delta > 1$ seems realistic. It is also for (3) to have sensible properties. Nevertheless, it is possible to choose $\delta = 1$ (logarithmic case) or even $\delta < 1$, additional assumptions on $i(s)$ are needed.
constant returns to scale production functions, with countries and locations modeled symmetrically.

4.1 Geographical space and goods space

Geographic space $S$ is understood as a continuum of locations (or: addresses) $s \in S$ organized along the circumference of a circle. We define regions (or: countries) as connected, ordered subset of $S$, with $S^j$ the collection of locations associated to region $j$. We let $j = 1, \ldots, J$, so that there are $J$ regions. Moreover, the partition of geographical space into regions is exogenous and perfectly symmetric. Hence, we may normalize the length of each region to unity. Clearly, $S = \bigcup_j S^j$ and the length of the world is just equal to $J$. Denote $\bar{x}_j$ as the address at the middle of each region. Figure 2 illustrates the situation.

At each location $s$ there is a representative household who inelastically supplies $m(s)$ units of labor. Households are immobile across space, so $m(s)$ is exogenous. We can leave the form of $m(s)$ open as long as $m(s) > 0$ for all $s \in S$ (no inhabited locations) and $m(s)$ is twice continuously differentiable. Moreover, locations may differ with respect to the topological circumstances. Hence, we have a distribution of productivities $q(s)$ which gives the rate at which resources are transformed into infrastructure investment goods. Again, we only restrict $q(s)$ to be twice continuously differentiable. To simplify notation, we refrain from using regional indexes until entering into political economy considerations.

At each location $s$, a homogeneous agricultural and a spatially differentiated industrial
good can be produced. Both types are produced with linear production functions (no
fixed costs) under conditions of perfect competition. Consumers consume both types,
perceiving industrial goods produced at specific locations as imperfect substitutes. There
are no costs of transporting the agricultural good. Moreover, the agricultural good serves
as an input into infrastructure provision. Each location \( s \) is home of consumers and
producers. We denote addresses of consumers by \( x \) and addresses of producers by \( z \).

We make a further important assumptions in relation to (3): The resource used to
produce infrastructure investment goods can be transported freely across space. This
assumption can be relaxed only at the price of considerable complication. It is similar
to the assumption of a costlessly tradable agricultural good in much of the economic
geography literature.

Infrastructure at address \( s \) is produced according to a linear production function
\( i(s) = b(s)/q(s) \) where \( b(s) \) denotes the input of the resource used for infrastructure
investment, and \( 1/q(s) > 0 \) measures the rate at which that resource is transformed into
infrastructure. The total economy-wide supply \( B \) of the resource required for investment
will be endogenously determined by government policy. Feasibility of an investment policy
\( i(s) \) implies that

\[
\int_{s \in S} q(s) i(s) \leq B. \tag{4}
\]

The above assumptions have the advantage that they deliver factor price equalization
across space as long as all locations produce both types of goods (which we assume). The
existence of the agricultural good as an input in infrastructure production makes thinking
about a transportation technology for transferring infrastructure production inputs from
one region to the other redundant.

4.2 Consumer behavior

The utility function of the representative household at location \( x \) is a Cobb-Douglas
aggregate over the homogeneous agricultural good and a Dixit-Stiglitz aggregate over
industrial goods,

\[
U(x) = \left[ c^A(x) \right]^{\alpha} u(x)^{1-\alpha}, \alpha \in (0, 1), \tag{5}
\]

\( c^A(x) \) denotes the total quantity of the agricultural good consumed at address \( x \), and
\( u(x) \) is the subutility index attributable to spatially differentiated goods. Let

\[
u(x) = \left[ \int_{z \in S} c^I(x, z)^\rho \, dz \right]^{\frac{1}{\rho}}, 0 < \rho < 1, \tag{6}\]

where \( c^I(x, z) \) is the quantity of a good produced at address \( z \) and consumed at \( x \).
Let $Y^n(x)$ denote household $x$’s net income in terms of a numéraire to be defined below. Then, the its budget constraint is

$$Y^n(x) = c^A(x)p^A(x) + \int_{z \in S} c^I(x,z)p^I(x,z)\,dz,$$

(7)

where $p^A(x)$ is the price of the agricultural good at location $x$ and $p^I(x,z)$ is the price of a variety imported from location $z$ and consumed at $x$.

Since preferences are separable in category $A$ and $B$ goods, we may solve the consumer problem as a two-stage budgeting problem. The Marshallian demand functions for varieties of categories $A$ and $B$ are respectively

$$c^A(x) = \frac{\alpha Y^n(x)}{p^A(x)}$$

and

$$c^I(x,z) = (1 - \alpha) Y(x) p^I(x,z)^\sigma,$$

(8)

where $\sigma = 1/(1 - \rho)$ and

$$P^I(x) = \left[ \int_{z \in S} p^I(x,z)^{1-\sigma} \,dz \right]^{1/\sigma},$$

(9)

is the price index for industrial goods.

The indirect utility attainable at prices $p^A(x), p^I(x,z)$ and income $Y^n(x)$ can be written as

$$\tilde{V}(x) = \alpha^\sigma (1 - \alpha)^{1-\alpha} [p^A(x)]^{-\sigma} [P^I(x)]^{-(1-\alpha)} Y^n(x),$$

(10)

where the term $Q(x) = [p^A(x)]^\alpha [P^I(x)]^{1-\alpha}$ can be interpreted as the cost of living index in the economy.

### 4.3 Firm behavior

At each location $z \in S$, the agricultural and the industrial good are produced under conditions of perfect competition. The only input of production is labor. Production functions for the two types of goods are linear

$$y^A(z) = bl^A(z), y^I(z) = l^I(z),$$

(11)

where $b > 0$ is a productivity parameter. Output quantities are denoted by $y^A(z)$ and $y^I(z)$, and labor inputs by $l^A(z)$ and $l^I(z)$, respectively. We assume that workers are perfectly mobile across agricultural and industrial firms. Hence, optimal firm behavior implies that $p^I(z) = w(z)$ and $p^A(z) = w(z)/b$, where $w(z)$ is the wage rate (expressed in units of numéraire) at address $z$. 

16
4.4 Equilibrium

Industrial goods bear transportation costs. Hence, the c.i.f. prices faced by consumers differ from the f.o.b. (ex-factory) prices. In particular, a consumer at \( x \) faces the price \( p^A(x,z) = p^A(z)T(x,z) \) for a variety of good imported from location \( z \). There are no trade costs other than transportation costs. In particular, there are no formal or informal barrier to trade at borders. In contrast, agricultural goods can be transported freely. We impose a non-full-specification (NFS) assumption: there is always a strictly positive quantity of agricultural production at each location. The NFS assumption introduces factor price equalization in terms of the agricultural good.\(^{13}\) We may therefore choose the agricultural good as the *numéraire* and set \( p^A(z) = 1 \) for all \( z \) and \( x \). Hence, \( Q(x) = P^I(x)^\alpha \). Since \( p^A(x) = 1 \), we drop the superscripts \( A \) and \( I \) in the following.

Profit maximizing firm behavior implies factor price equalization, i.e. \( w(z) = b \) at every location. Income at location \( x \) in terms of the numéraire is then \( Y(x) = bm(x) \). From our assumption on technology, \( p(z) = b \) so that c.i.f. prices for industrial goods are

\[
p(x,z) = bT(x,z).
\]

The government imposes a lump-sum tax \( t \) which is assumed identical across addresses \( s \in S^c \) which fall into the reach of the government. In terms of the numéraire good, total tax income is \( B = bt \int_{s \in S^c} m(s) \). Hence, \( Y^n(x) = (1-t)bm(x) \).

We may now rewrite indirect utility function (10) per member of the representative household:

\[
V(x) = \Omega (1-t)^{\frac{\sigma-1}{\alpha}} m(x)^{\frac{\sigma-1}{\alpha}-1} \int_{z \in S} T(x,z)^{1-\sigma} dz
\]

where \( \Omega \equiv [(1-\alpha)b^\frac{\alpha^\sigma}{\alpha-1}(1-\alpha)^\sigma]^{\alpha-1} \) is a function of exogenous parameters only and \( V(x) = \tilde{V}(x)^{\frac{\sigma-1}{\alpha}} \) is a positive transformation of \( \tilde{V}(x) \).

In order to facilitate notation, we define the following sets of addresses:

\[
L(r) = \{ z \in S : z \leq r \} ,
\]

\[
R(r) = \{ z \in S : z \geq r \}.
\]

The set \( L(r) \) collects all addresses of producers that are relevant to utility and that lie to the the left of some specific location \( r \), while \( R(r) \) collects all such addresses that lie to the right of location \( r \) that

\(^{13}\)Relaxing the NFS assumption would allow to study the interaction between infrastructure investment policies and regional specialization patterns. This is an interesting issue that rises additional complications. It is therefore left to future research.
Using this notation, we may define $F^{L(x)}(x) = \int_{z \in L(x)} T(z, x)^{1-\sigma} \, dz$, $F^{R(x)}(x) = \int_{z \in R(x)} T(x, z)^{1-\sigma} \, dz$, and $\int_{z \in S} T(x, z)^{1-\sigma} \, dz$. Clearly, $S = L(x) \cup R(x)$ and $L(x) \cap R(x) = \emptyset$.

Note that $F(x) = [b/P(x)]^{\sigma-1}$, so $F(x)$ is negatively related to $P(x)$. Therefore, we interpret the terms $F^{L(x)}(x)$, $F^{R(x)}(x)$ and $F(x)$ as measures of gross indirect utility attained by agent $x$ over goods in $L(x)$, $R(x)$ and $S$, respectively. We rewrite indirect utility as

$$V(x) = \Omega(1-t)^{\frac{\sigma-1}{\sigma}} m(x)^{\frac{\sigma-1}{\sigma}} \left[ F^{L(x)}(x) + F^{R(x)}(x) \right]$$

(14)

Costless tradability of category $B$ varieties effectively equalizes wages in terms of the numéraire. It also pins down ex-factory (f.o.b.) prices $p(z)$ directly. Unlike in the standard Armingtonian setup, locations with a larger mass of workers do not suffer from lower terms of trade, since $p(x)/P(x)$ is independent from the distribution of economic activity across space $m(s)$. The reason is that a higher supply of workers is absorbed by an expansion of the agricultural sector at constant marginal value productivity.

5 The political economy of infrastructure investment

This section presents the core results of the model. As mentioned above, the world is modeled as a circle, while individual countries are segments on that circle. Alternatively, one may think of the circle as a relatively closed country, with segments representing autonomous regions within that country. The rationale behind many results in the following analysis is the discrepancy between the political and the economic reach of countries: while infrastructure investment decisions are limited to subsets $S^c$ of space, consumers demand imports from all countries and locations. Since countries decide in a non-cooperative way, they do not internalize the positive externality that their investment decisions exert on consumers in other countries. This leads to global underprovision of infrastructure. More importantly, it also leads to excessive spatial variation in infrastructure relative to the first best solution, since the externality has different size at different addresses within a region.

![Figure 3: Agents located in $[-b, s]$ benefit through goods imported from $[s, b]$ while agents in $[s, b]$ benefit through goods from $[-b, s]$.](image_url)
In the following, first the autarkic equilibrium is discussed. In that case, consumers cannot consume goods produced in countries other than their own. This is hence a situation where trade restrictions are prohibitive. Alternatively, one may interpret this case as the solution to the infrastructure provision problem if the decision maker acts for the entire world, but the world is a line instead of a circle. We will show that under the assumptions made in section 4 the median voter problem leads to qualitatively similar results than the central planner solution. Then, we present the solution to the political economy problem for a circular world which is fragmented into many countries. We compare the world-planner solution to the outcome that obtains if infrastructure decisions are undertaken by independent countries. We show that the qualitative shape of the world infrastructure distribution will be robust to the details of the political economy process and whether or not the political actors take into account how their decisions affect decisions of agents in other countries.

In the following sections we will characterize optimal policies \( \hat{i}(s), \hat{t} \) \( s \in [0,1] \) under different assumptions. More precisely, we distinguish between autarky outcomes obtained by a median voter and a social planner, as well as situations where countries are open to trade but fragmented politically. In that latter case we describe the world planner outcome and the result that materializes in a median voter and a social planner environment.

### 5.1 Political economy equilibrium under autarky

We let the relevant economic space be a line \([0,1]\). In contrast to the circular case, the linear geography exhibits a natural periphery in the sense that peripheral regions will have higher average transportation costs and hence lower indirect utility. Note, however, that even in that case, the assumptions made in section 4 allow us to set \( p(z) = 1 \). In the following, a uniform spatial distribution of population is assumed, hence \( m(s) = 1 \) for all \( s \). Since the length of a country is normalized to unity, gross income in terms of the numéraire good is \( b \) in each country. It is straightforward, albeit cumbersome, to allow for variation in \( m(x) \) over space. The robustness of the main results of the paper to this specific assumption is discussed below.

#### 5.1.1 Preferred policies across households

First, we need to establish each household’s preferred infrastructure distribution \( i^x(s) \) and total infrastructure spending \( t^x \). Note the superscript \( x \) which indicates the optimality from the perspective of a household at address \( x \) (referred to as household \( x \) for simplicity).
The program that household $x$ solves is
\[
\{i^x(s), t^x\} = \arg \max \left\{ \Omega \left( 1 - t \right)^{\frac{\alpha}{\sigma}} F(x) \quad \text{s.t.} \quad tb \geq \int_0^1 q(s) i(s) \, ds \right\},
\] (15)
where $Y = b$ is total income available in the region, $F(x) = \int_{z \in L(x)} T(z, x) \, dz + \int_{z \in R(x)} T(x, z)^{1-\sigma} \, dz$ and $\tau(x, z)$ is defined in (3). Each agent balances the gain in utility of a marginal increase in the stock of transport infrastructure at location $s$ against the associated cost. Solving (15), we derive the first proposition.

**Proposition 1** Let an agent at address $x$ choose a tax rate and the the optimal allocation of infrastructure for the region $[0,1]$. Her optimal infrastructure investment profile obeys the following continuum of first order conditions
\[
i^x(s) = \begin{cases} (1 - \alpha) b \phi^L(x, s) \frac{1+1}{q(s)} & \text{if} \quad s \in L(x) \\ (1 - \alpha) b \phi^R(x, s) \frac{1+1}{q(s)} & \text{if} \quad s \in R(x) \end{cases}
\]
for all $k \in [0,1]$, where
\[
\phi^L(x, s) = \frac{F^L(s)(x)}{F(x)} \quad \text{and} \quad \phi^R(x, s) = \frac{F^R(s)(x)}{F(x)}
\]

**Proof** See the Appendix.

The terms $\phi^L(x, s)$ and $\phi^R(x, s)$ measure the share of gross indirect utility derived from goods that transit through the location $s$ relative to total gross indirect utility $F(x)$. A higher importance of industrial goods $1 - \alpha$ in the utility specification (6), or a higher productivity $b$, lead to higher investment. Moreover, the larger the shares $\phi^L$ and $\phi^R$, the higher will optimal infrastructure investment be. Note that for agents with addresses $0 < x < 1$, we have $\phi^L(x, 0) = \phi(x, 1) = 0$. Hence all of those agents prefer zero investment at the borders: $i^x(0) = i^x(1) = 0$. If $x = 1$ only the first line in the above expression is relevant, and $i^1(1) > 0$ while $i^0(0) = 0$. Similarly, $i^0(0) > 0$ and $i^0(1) = 0$. One can totally differentiate that expression and find that a marginal increase in $q(s)$ unambiguously leads to a reduction in the amount of investment at address $s$. Also, an increase of $\sigma$ beyond unity lowers $i^x(s)$ as agents perceive varieties as closer substitutes.

Differentiating $i^x(s)$ with respect to $s$ we can characterize the behavior of $i^x$ over space.

**Proposition 2** The proportional spatial growth rate of infrastructure investment that is optimal from the perspective of an agent residing at address $x$ is given by
\[
g^x(s) = \frac{i'^x(s)}{i^x(s)} = \begin{cases} \frac{1}{\delta} \left[ \frac{F^L(s)(x)}{F(x)} - \frac{q(s)}{q(1)} \right] & \text{if} \quad s \in L(x) \\ -\frac{1}{\delta} \left[ \frac{F^R(s)(x)}{F(x)} - \frac{q(s)}{q(1)} \right] & \text{if} \quad s \in R(x) \end{cases}
\]
for all $s \in [0,1]$. (16)
For \( q^\prime (s) = 0 \), \( i^x (s) \) is strictly concave and continuous over the intervals \([0, x)\) and \((x, 1]\).

**Proof**  
See the Appendix.

The proportional rate at which the stock of infrastructure investment changes across space is a function of \( 1/\delta \), the elasticity of interregional substitution of infrastructure investment. The higher that elasticity, the faster will \(|g^x (s)|\) decline as we move away from agent \( x \)'s address. The reason for this result is straightforward: Consider a spending-neutral perturbation of some optimal investment schedule \( i^x (s) \) by \( di (s') > 0 \) and \( di (s'') < 0 \), such that \( q (s') = q (s'') \) and \(|x - s'| < |x - s''|\). A marginal increase in investment at the point close to agent \( x \), \( s' \), has the advantage that more shipments to \( x \) will transit through that point. Hence, the cumulative impact of \( di (s') \) will be larger than \( di (s'') \), so that the proposed perturbation increases \( x \)'s utility. However, thinning out investment at \( s'' \) comes with a cost, as higher investment at \( s' \) is an incomplete substitute for investment at \( s'' \). If \( 1/\delta = 0 \), i.e., investments at different points at perfect complements, then agent \( x \) desires a flat infrastructure distribution: higher investment close to the own location is useless if investment is not increased also at other locations. However, if \( 1/\delta = \infty \), investments at different points are perfect substitutes. Then, there are no costs from reallocating investment close to \( x \)'s address. The cumulative effect dominates, and agent \( x \) wants to invest exclusively in a neighborhood of her own address.

Note that in the above expression, the address \( s \) describes the location from which goods are shipped to \( x \). Hence, the two cases \( s \leq x \) and \( s \geq x \) refer to imports of agent \( x \) from locations at her left and her right, respectively. Expression (16) allows a number of interesting expressions. First, the absolute value \(|g^x (s)|\) at which any agent wants to vary her preferred stock of infrastructure over time increases in the interregional elasticity of substitution, \( 1/\delta \).

Assuming that geographical space is perfectly flat on the interval \([0, 1]\), i.e., that there are no natural obstacles (rivers, mountains) that would warrant variation of \( q (s) \) over space, we have \( q^\prime (s) = 0 \) for all \( s \in [0, 1] \). Then spatial variation in the desired level of infrastructure investment is governed only by variation in the terms \( T (s, x)^{1-\sigma} / F^{L(s)} (x) \), and \( T (x, s)^{1-\sigma} / F^{R(s)} (x) \) respectively. Focusing on the latter case (the former is perfectly symmetric) it is easy to show that \( \partial g^x (s) / \partial s < 0 \), so that \( i (s) \) is a decreasing and concave function of \( s \). Moreover, \( \partial g^x (s) / \partial x > 0 \), so that the decline rate of the desired stock of infrastructure across space is less negative for households closer to \( s \). This allows to trace the desired investment schedules, see figure 4.\(^\text{14}\)

\(^{14}\)Note that we have characterized \( i^x (s) \) through the partial differential equation (pde) given by \( g^x (s) \).
Figure 4: Address-specific preferred investment profiles.

The functions $i^x (s)$ are piecewise differentiable and continuous over the intervals $[0, x]$ and $[x, 1]$ and that are non-differentiable at the address $x$ and (except for the median agent) discontinuous. Note that the growth rate $g^x (x)$ is not defined; moreover, $i^x (x) = 0$ since varieties produced at the own address can be shipped with zero cost regardless of the stock of infrastructure investment at $x$.

Still holding $q' (s) = 0$, total infrastructure spending desired by agent $x$ can be measured as the total area below the curves $i^x (k)$. It is straightforward to show that (see the appendix)

$$t^x = \inf \{t^x \}, x \in [0, 1],$$

(17)

where $\bar{x}$ denote the average (median) address (in the present case $\bar{x} = 1/2$).

In the more general case, where $q (s)$ is allowed to vary across space, we have to make explicit assumptions about the function $q (s)$. The simplest case is the one where $q (s)$ is a symmetric function over the interval $[0, 1]$, reaching an extremum at $\bar{x}$ and growing monotonically at a constant rate $\frac{q'(s)}{q(s)} = g_q$ at points different than the one where the extremum is reached.

The plot in figure 4 is a plausible solution to that pde.
If \( q(s) \) reaches a minimum at \( \bar{x} \), the situation depicted for \( i^{\bar{x}}(s) \) in figure 4 holds a fortiori: the spatial variation in the cost of providing infrastructure investments adds to the natural tendency towards concentration at \( \bar{x} \), resulting in steeper slopes of \( i^{\bar{x}}(s) \). For agents other than \( \bar{x} \) the situation is more complicated. Agents to the left of \( \bar{x} \) would choose a steeper slope of \( i^{x}(s) \) for \( s < x \) while reverting to an S-shaped curve with high slope close to \( s = x \) and \( s = 1 \) for locations \( s > x \).

If \( q(s) \) reaches a maximum at \( \bar{x} \), spatial variation in \( i^{\bar{x}}(s) \) is lower. Now, the sign of expressions (16) can change, giving rise to a U-shaped infrastructure distribution across space. It could also be that the growth rates \( g^{x}(s) \) are exactly equal to zero due to the variation in \( q(s) \).

Finally, consider the case where geography is essentially flat, \( q(s) \) is constant for all \( s \) except one location \( s' \) where \( q(s') \) is very high. This situation could capture the effect of a river. Because agents want to smooth infrastructure investment over space, the local geographical disturbance at \( s' \) virtually leaves preferred total spending and the distribution of investment across space unchanged. This is an extremely important property that we will need later when we turn to the interpretation of the global political economy outcome.

All these examples suggest that the interior geography of countries is important to understand the allocation of infrastructure investment. However, geography has only a limited role to undo the central tendency that agents want to concentrate investment close to their home addresses and that peripheral agents tend to prefer larger total investment volumes than central ones. For that reason, we set \( q'(s) = 0 \) for the remainder of the theoretical discussion. In empirical applications, one would however take natural variation in the cost of investment into account.

### 5.1.2 Median voter outcome

We denote by \( V^{x'}(x'') \) the indirect utility obtained by household \( x' \) if the infrastructure allocation and tax rate preferred by agent \( x'' \) is implemented across the country. Clearly, \( \Delta = V^{x'}(x') - V^{x'}(x'') \geq \), for all \( x', x'' \in [0,1] \), since \( V^{x}(x) \) is a maximum value function. It can be easily seen (and formally shown) from figure 1 that strict concavity of the \( i^{x}(s) \) functions implies that

\[
\frac{\partial \Delta (|x' - x''|)}{\partial |x' - x''|} > 0.
\]

However, in this context the additional variation in \( i(x) \) is caused by geographic fundamentals and therefore need not be associated to a deterioration in welfare.
Hence, a larger geographical distance between \( x' \) and \( x'' \) implies that the utility loss suffered from adopting the other agent’s preferred policy is larger. Hence, preferences are single peaked over the continuum of policies preferred by agents residing at addresses \([0, 1]\). It follows that bilateral referenda would bring out the median voter’s preferred policy as the political equilibrium.

Hence, the equilibrium policy \( \{ \hat{i}_0(s), \hat{t}_0 \}_{s \in [0, 1]} \) obtained in a median voter setup under autarky is given by

\[
\hat{i}_0(s) = i^x(s), \hat{t}_0 = t^x. \tag{19}
\]

5.1.3 Central planner problem

Next, we turn to the solution to the social planner problem for the case of autarky. The planner’s objective function is an unweighted aggregate of the indirect utility positions achieved at every address. Total welfare than is

\[
W = (1 - t) \int_0^1 F(x) \, dx.
\]

We denote the optimal policy in that context as \( \{ i^a_0(s), t^a_0 \}_{k \in [0, 1]} \). Accordingly, the planner problem is

\[
\{ i^a_0(s), t^a_0 \} = \operatorname{arg\ max} \left\{ \Omega (1 - t) \frac{z - 1}{\alpha} \int_0^1 F(x) \, dx \mid bt \geq \int_0^1 q(s) i(s) \, ds \right\}. \tag{20}
\]

Proposition 3 The optimal allocation of infrastructure spending across space chosen by a social planner under autarky is implicitly determined by the continuum of first order conditions

\[
i^a_0(s) = \frac{\alpha (1 - t^a_0) b}{q(s)} \left[ \phi^L(s) + \phi^R(s) \right], \quad \text{for all } k \in [0, 1],
\]

where \( \phi^L(s) \) and \( \phi^R(s) \) are generalized versions of the terms \( \phi^L(x, s) \) and \( \phi^L(x, s) \), respectively, defined in Proposition 1.

Proof See the Appendix.

The terms \( \phi^L(s) \) and \( \phi^R(s) \) denote the share of gross welfare derived from industrial products delivered from places to the left and the right of location \( s \), respectively. Since \( \phi^L(1) = \phi^L(0) = \phi^R(1) = \phi^R(0) \), investment is zero at the borders of the region. It is higher the larger the sum \( \phi^L(s) + \phi^R(s) \), which measures the total gross welfare that stems from varieties that flow through point \( s \).

Note that, in contrast to individual preferred policies, the first order condition of the central planner is not discontinuous since the planner integrates over all individual utility positions, thereby smoothing out the discontinuities.
Proposition 4  The proportional spatial growth rate of infrastructure spending across space chosen by a social planner under autarky is given by

\[ g_a^0 (s) \equiv \frac{i_a^0 (s)}{i_a^0 (s)} = \frac{1}{\delta} \left[ \frac{\sigma - 1}{\delta - 1} i (s)^{1-\delta} \Delta (s) \int_s^1 \int_s^1 T (z, x)^{1-\sigma} dz dx - q' (s) \right], \tag{21} \]

where \( \Delta (s) \equiv \int_s^1 T (s, x)^{1-\sigma} dx - \int_s^0 T (x, s)^{1-\sigma} dx. \)

Proof  See the Appendix.

In the case where \( q' (s) = 0 \), the sign of \( g_a^0 (s) \) depends only on the sign of \( \Delta (s) \). It is easy to show that \( \Delta (0) = \int_0^1 T (0, x)^{1-\sigma} dx > 0 \) and \( \Delta (1) = - \int_0^1 T (x, 1)^{1-\sigma} dx < 0 \), \( \Delta' (s) < 0 \), and \( \Delta (1/2) = 0 \). Hence, \( g_a^0 (s) > 0 \) for \( s \in [0, 1/2] \), \( g_a^0 (1/2) = 0 \), and \( g_a^0 (s) < 0 \) for \( s \in (1/2, 0] \). Moreover, \( g_a^0 (0) \to \infty \) while \( g_a^0 (1) \to -\infty \) as the denominator in (21) tends to zero. One can show that \( i_a^0 (s) \) is strictly concave in \( s \) (see the appendix). Figure 4 shows the social planner’s investment profile across space.

Hence, the distribution of infrastructure investment chosen by the social planner under autarky is qualitatively similar to the outcome obtained under the median voter scenario. One key difference is that \( i_a^0 (s) \) is now continuously differentiable at all locations. This reflects the investment smoothing property highlighted in section ??.

It is difficult to obtain clear comparisons of the social planner outcome \( i_a^0 (s) \) and the one chosen by the median voter. In general, the median voter solution displays an inefficient distribution of infrastructure across space, since it does not satisfy the investment smoothing property. However, whether the median voter over- or underinvests depends on model parameters. The higher the degree of substitution, \( \sigma \), between varieties, the more likely is underinvestment. In the limiting case, where \( \sigma \to 1 \) (Cobb-Douglas utility), there is overinvestment in the median voter case. Hence, total spending in the central planner case strictly lies below that desired by any agent in the median voter case. The reason for this is clear enough: if agents can impose tax rates for the entire economy, the will tend to chose high ones but since they have the power to decide on the spatial distribution of infrastructure investment, they will concentrate investment close to their home addresses.

5.2 Political economy equilibrium under international trade

We now turn the situation where the world economy is a collection of independent countries, each with its own government that decides on infrastructure investment in a non-cooperative way. However, consumers demand goods produced all over the world. We
have therefore a situation with ‘global market, regional politics’. With a uniform dis-
tribution of infrastructure investment, unlike in the autarky case discussed above, there
would not be a natural periphery in spite of non-zero variable transportation costs.

If investment were to be decided on the world level, the median voter problem is not
well-defined since all agents would opt for the same investment profile, which would again
be a hump-shaped function with zero investment at the (zero-mass) point with maximum
distance to the median voter’s address. Hence, we focus on the world central planner
problem first and then compare it to the outcomes obtained. With single jurisdictions,
the median voter problem is still well-defined and we present both, the median voter and
the central planner investment solution. Notice that we will now focus on cases where
$q'(s) = 0$ and remember that we are assuming a uniform distribution of economic activity
on the circle.

5.2.1 World planner problem

The world planner chooses the world infrastructure profile to maximize the indirect utility
of the entire world population, optimizes infrastructure investment over problem, the
space across which individuals trade and over which infrastructure decisions are made
coincide. Hence, we have one market and one jurisdiction that decides over infrastructure
investments. The world planner problem can be written as

$$\{i^*_0(s), t^*_0\} = \arg \max \left\{ \Omega \left(1 - t^*_0 \right)^{\frac{\alpha - 1}{\alpha}} \int_{x \in S} F(x) \, dx \, \left| \begin{array}{c} b \geq \int_{x \in S} q(s) \, i(s) \, ds \end{array} \right. \right\}$$ (22)

Proposition 5 The solution to the world planner problem is characterized by the
following continuum of first order conditions

$$i^*(s)^{\delta} = \frac{(1 - t^*)}{\int_{s \in S} F(x) \, dx \, q(s)} \cdot \frac{1}{1}, \text{for all } s \in S$$

The optimal spatial investment profile reflects only the spatial distribution of investment
costs. With $q'(s) = 0$, the optimal distribution is uniform.

Proof See the Appendix.

Clearly, with $q'(s) = 0$, the distribution of infrastructure investment across space is
uniform, with its level depending only on the price of investment goods, the size of the
world (i.e., the circle) and $\delta$. 
This result is quite intuitive. Perfect symmetry plus uniform distribution of activity implies that transit volume at every address is identical. Since the world planner does not discriminate between traffic directed towards different addresses, she will naturally chose \( i^*(s) = i \) for all \( s \in S \). Note also that this result is a natural application of the investment smoothing property of \( \tau \) discussed above.

### 5.2.2 Global economy, regional politics

In this section we discuss the solution of a game between different jurisdictions, which each set policies \( \{i^j(k); t^j\}_{k \in S^j} \), where \( j \in J \) now indicates the jurisdiction. For the sake of simplicity we assume that those policies are set by social planners. Note however, that the median voter setup would run into problems if we allow for strategic interactions between countries. The reason is that when contemplating their preferred policies voters would have to think about the strategic implications of their decisions. This would force them to make conjectures also about what agent’s policy would be implemented in any other country. They would have to conclude that it would be the median’s preferred policy. We avoid these complications by choosing the social planner setup.

Now, we have to make a basic dissociation between jurisdiction-specific policies, which are defined over the set \( S^j \), and optimal demand functions defined over export country locations in \( S \). We set \( q(s) = 1 \); hence, all jurisdictions are symmetric and we may therefore restrict the solution space to symmetric infrastructure distribution functions and tax rates.

Denote the optimal infrastructure policy in jurisdiction \( j \) is \( \tilde{i}^j : \bigcup M \to M \) where \( M \) is the (Banach) space of non-negative and continuous functions. Then, we may write the best response of the planner in region \( j \) as a function of

\[
\tilde{i}^j(s) = G \left( \left\{ \tilde{i}^k(s) \right\} \right) \equiv \arg \max \left\{ \int_{s \in S^j} F[i^x(x)] \left( 1 - t^j[i^x(x)] \right) dx \bigg| \left\{ \tilde{i}^k(s) \right\}_{k \neq j, s \in S^j} \right\}, \text{ for all } j \in J, \tag{24}
\]

where we stress the dependence of \( F \) on the world distribution of infrastructure investment.

We may now represent the symmetric equilibrium infrastructure allocation chosen by all planners as the solution to the fixed point problem

\[
G \left( \left\{ \tilde{i}^x(s) \right\} \right) = \tilde{i}(s), \tag{25}
\]

where the world equilibrium allocation of infrastructure is the collation \( \bigcup_{j \in J} \tilde{i}^j(s) \).
The proof of existence and unicity of \( \tilde{r}(s) \) follows Rossi-Hansberg (2003). In particular, existence is shown by an application of Schauder’s fixed point theorem, which requires that the functions \( F[i(s)](1 - t^j) \) are bounded, differentiable and continuous with respect to other jurisdictions’ policies, which they trivially are in the present context.\(^{16}\)

Unicity can be shown under the additional assumption that the equilibrium infrastructure distributions functions are continuous themselves.\(^{17}\) We summarize the properties of the equilibrium world allocation of the infrastructure investment distribution, \( \tilde{i}(s) \), in the next proposition.

**Proposition 6** Let \( \bar{x}^j \) denote the mean (=median) address in jurisdiction \( j \). First, \( \tilde{i}'(\bar{x}^j) = 0 \) for all \( j \in J \). This means that as in the autarkic social planner problem, local maxima are attained at median addresses in each jurisdiction. Second, \( \tilde{i}'(s) > 0 \) for all \( s \in [\bar{x}^j - 1/2, \bar{x}^j] \), \( j \in J \) and \( \tilde{i}'(s) < 0 \) for all \( s \in [\bar{x}^j, \bar{x}^j + 1/2] \), \( j \in J \). Third, \( \tilde{i}(\bar{x}^j - 1/2) = \tilde{i}(\bar{x}^j + 1/2) = \Gamma(\delta) > 0 \), which shows that \( \tilde{i}(s) \) is symmetric around the median address. We may therefore conclude that \( \tilde{i}(s) \) is a perfectly symmetric wave function, \( s \in S \), on the circle.

**Proof** See the Appendix.

Figure illustrates Proposition 6.

### 6 Tentative empirical evidence

#### 6.1 Testable implications from the model

The model has a range of predictions that can be put to an empirical test. In this section we discuss a number of those predictions without going into much detail. Appropriately discretized spatial data on intra- and international trade flows, associated to economic variables such as GDP, and direct information on the quantity and quality of transport infrastructure is difficult to construct and raises a number of important econometric issues, for example, related to spatial correlation of error terms.

The model also has interesting predictions relating to the effects of preferential trade liberalization. Infrastructure investment should be skewed towards that border which is economically permeable. Subsequent waves of EU enlargement could be used to check this hypothesis.

---

\(^{16}\)See also Ok, Ch. J.

\(^{17}\)The assumptions used to show existence and uniqueness are unnecessarily strong, but are anyway satisfied under our functional assumptions.
The model could also be brought to a calibration exercise. Standard new economic geography models predict economic inequality, but require the existence of natural peripheries. Our argument would allow economic inequality across space even in circumstances where no natural periphery exists, and borders have exclusively political significance. Calibration exercises of the standard models often lead to simulated inequalities statistics that are too low compared to the data. Allowing for the endogenous allocation of $i(s)$ across space could help improve this fit.

Straightforward testing of the proposed model requires data on the quantity and quality of transport infrastructure across space. The actual distribution could then be compared to the distribution generated from a version of the model, where at least $m(s)$ is taken from real data. However, continuous data on $i(s)$, $m(s)$ or $q(s)$ is not available, hence, one has to discretize. This leads to a number of complications whose discussion we relegate to a full-fledged empirical analysis of the proposed model to future research.

In the present paper, we use a gravity-type estimation strategy to check whether easily available data for intra-US trade is consistent with our major result. While this ‘test’ is of limited reach, it nevertheless delivers results consistent with the model. However, any reasonable test of the model will have to relax the simplifying assumptions of a uniform distribution of population and investment prices adopted in the above analysis. We have already discussed what happens if $q(s)$ is not uniformly distributed and concluded that spatial variation in $q(s)$ needs to be very strong in order to undo the core results in
our model. Similar considerations hold if \( q(s) \) and \( m(s)^{-1} \) are distributed in the same non-uniform manner. In the extreme case, where all agents are concentrated at \( \bar{x} \) so that \( m(s) = 0 \) if \( s \neq \bar{x} \), the government would want to choose a infrastructure distribution much the same as individual agents would in the results presented in section , hence, \( i(s) \) would have a hump-shaped form if the concentration of the mass of agent does not occur exactly at a border. If agents would locate arbitrarily close to borders, we would observe a U-shaped distribution of \( i(s) \). However, it is clear that controlling for \( m(s) \), we would recover our results, as investment beyond the benchmark of a uniform distribution would again take a hump-shaped form.

6.2 A gravity equation application

In the following empirical exercise, we want to explore data on US internal trade. We can test the above model using this specific data, since data from foreign countries is not necessary to check some of the predictions of the model. We now turn to the gravity equation that emanates from the structure of the model. Starting from the demand function for industrial goods (8), substituting for \( p(x,z) \) and the price index by (9) and (12), and recognizing that \( Y^n = (1-t) m(x) b \), it is possible to derive an expression for the c.i.f. value of trade from \( z \) to \( x \):

\[
X(x,z) = (1-\alpha) (1-t) m(x) b^{1-\sigma} \frac{T(x,z)^{1-\sigma}}{\int_{s \in S} T(x,z)^{1-\sigma} dz^{1-\sigma}} \text{ for } z \geq x. \tag{26}
\]

The value of bilateral trade in industrial goods between \( x \) and \( z \) is a rather complicated function of the income of region \( x \), \( m(x) b \), and on the distribution of infrastructure in the interval \([x,z]\) which, in turn, shapes the cost factors \( T(x,z) \). However, the comparative statics with respect to distance is relatively simple. The bilateral trade volume (26) between \( x \) and \( z \) depends on distance only through the term \( T(x,z)^{1-\sigma} \). We may therefore write \( X(x,z) = K(x) T(x,z)^{1-\sigma} \). Denoting the elasticity of \( X \) with respect to distance by \( \varepsilon(x,z) \), we have

\[
\varepsilon(x,z) \equiv \frac{\partial X(x,z)}{\partial z} \frac{z}{X(x,z)} = -\frac{\sigma-1}{\delta-1} z^{\delta-1} T(x,z)^{1-\delta} < 0.
\]

Clearly,

\[
\frac{\partial \varepsilon(x,z)}{\partial i(z)} = (\sigma - 1) z^{\delta-1} T(x,z)^{-\delta} > 0,
\]

so that the marginal effect of an increase in distance depends positively on the stock of infrastructure invested at the marginal location. The higher that stock, the smaller the
Hence, the spatial variation in $i(s)$ translates directly into variation of $\varepsilon$. The equilibrium distribution function $i(z)$ achieves a series of local minima at border points. Hence, $\varepsilon(x,z)$ is more negative the closer $z$ is to the border and is minimum at the border.

When bringing the theoretical model to the data, one has to discretize space. Data availability dictates how fine the grid of discretization can be. In the following empirical, distance to the closest border is proxied in a rather crude way by distinguishing between border regions and regions in the interior of the US. We keep, for the sake of simplicity, a uni-dimensional description of space. Let there be four regions in the US: two border regions and two central regions, as shown in figure 6.

Let $i_b$ and $i_c$ be the average stock of infrastructure investment in border and in central regions, respectively. Further, let $x', x''$ be addresses in the interior of the US, and $z', z''$ be addresses in border regions. Let all these addresses be equidistant. Then, the model predicts that

$$\varepsilon(x', x'') > \varepsilon(x', z') \approx \varepsilon(x'', z') \approx \varepsilon(x'', z'') \geq \varepsilon(z', z'').$$

(27)

6.3 Data and empirical strategy

We use data on bilateral trade volumes between US states for 1993. This data has been used by Anderson & van Wincoop (2003) and is extensively discussed in that article. The focus on the US follows from the fact that Canadian provinces are excessively large and have almost always a North–South extension that makes almost all of them border states.

---

\(^{18}\)Note the role of the elasticity of substitution $\sigma$ between varieties of the industrial good. We have constrained $\sigma > 1$ in (6) when we have specified the utility function. Usually, with monopolistic competition, this assumption is required to ensure that the monopolists’ decision problems are well defined. With perfect competition, however, this is not necessary. However, we need the assumption $\sigma > 1$ to ensure that the c.i.f. value of trade declines in iceberg costs.
In order to check a discretized version of (26), we run a standard gravity equation with importer/exporter fixed effects and usual covariates to explain intra US trade volumes. The model predicts that infrastructure investment is lower in border regions than in interior ones, hence trades involving border regions should be affected by a larger distance elasticity. For a formal empirical test, we interact the border-region dummy with the log of distance and see whether it turns out whether the absolute value of the elasticity of distance \( \varepsilon (x, z) \) is indeed more negative for trades where either \( x \) or \( z \) or both belong to border regions. Note that the estimated elasticities are conditional on distance, regional GDPs, and the density of population in each state.

6.4 Results

Table 3 shows the results of our regression. Column (1) shows the results of a very standard gravity equation with importer and exporter fixed effects. These fixed effects are meant to capture all unobserved state specific variables that may be important for the determination of bilateral trade volumes. Most importantly for the economic environment at hand, they control for differences across states in infrastructure investment relating to non land-borne transit, e.g., air traffic.\(^{19}\) A bunch of control is included to control for geographical variation in economic activity and the price of infrastructure investment. GDP measures are country specific and would drop out of the equation if the panel were balanced. It is not, which explains why they show up in the table. However, their estimates take values close to unity, which is exactly what gravity theory would predict. Also the distance elasticity, which can be interpreted as an average over interior and border regions takes a value very close to what the literature finds. All covariates are estimated with substantial precision, delivering an overall \( R^2 \) statistics of 94 percent.

Column (2) shows that \( \varepsilon (x', x'') = 0.884 \) and \( \varepsilon (z', z'') = 1.078 \), with both estimates significantly different from each other. Hence, a marginal increase in distance hurts significantly more for trade relations that involve only border states than for trade relations involving only central locations. This finding is consistent with the proposed literature. Note, however, when the model is estimated without fixed effects (column (3)), the interaction term still takes the same sign and similar size, but is no longer statistically different from zero. This is expected, see the recent discussion on the correct specification of the gravity equation (Anderson and van Wincoop, 2003, or Feenstra, 2004, p. 161 ff).

---

\(^{19}\)They also control for interregional differences in multilateral resistance indexes, see Anderson and van Wincoop (2003) or Feenstra (2004) for more details on the econometric foundation of the specific version of the gravity equation used here.
Columns (4) and (5) show that in line with theory, trade relations that involve only one border region have distance elasticities lying in the interval \( [\varepsilon (x', x''), \varepsilon (z', z'')] \), namely 1,003 and 1,076. While the latter estimate is close to the one obtained for both partners being border regions, column (4) and (5) can still be interpreted as lending additional support to the theoretical model.

The presented econometric evidence is suggestive, but not more. There are a couple of problems that relate to the discretization of economic space into unevenly designed states. Ideally, one would run a model where the distance coefficients are interacted with a measure of distance to the border. Continuous space trade data being unavailable, the researcher has to make compromises. However, drawing on European NUTS or US county level data, one could expect to make more precise inference than using state level data.

7 Extensions, Conclusion

7.1 Extensions

Toll taxes. In reality, many countries operate toll taxes for freight traffic. The ratio of interregional highways subject to decentrally administered toll systems ranges from 6 percent to 52 percent in France.\(^{20}\) Countries such as Germany and Austria have centrally administered distance dependent road pricing for lorries. User fees may be contingent on a wide array of factors such as the situation of the environment (e.g., smog), the degree of congestion, the time at which a road is traveled (fees may be higher for travel during night or weekends), or whether an sensible region is crossed (e.g., some protected zone).

How a toll system affects the main argument in this paper depends very much on its specific design. Suppose, the government decides on the infrastructure allocation across space, but rather than taxing consumers through lump-sum taxes, it taxes road users without discriminating between home- or foreign-bound transport. This kind of taxation is of course distortionary, since it will affect goods prices of the regional and the world economy. Further assume that the fee may vary continuously on the space of addresses and that it works just as our iceberg transportation costs, albeit with the shaved transported good not lost but transferred into the governments coffers. In that case, the government has two margins of action: it sets a distribution of fees, \( f (s) \), \( s \in [0, 1] \) and decides on the infrastructure allocation, \( i (s) \). Total income from fees will be \( B = \int_0^1 f (s) X (s) \, ds \), where \( X (s) \) is the value of goods, measured at ex-factory prices, that are transported through the

\(^{20}\)Data from 1998 for France (Combes and Lafourcade, 2005), and 2006 for the US.
Table 4: Trade flow elasticity of distance is higher if peripheral regions are involved

Within US trade, 1993

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ln Distance</td>
<td>-0.957&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-0.884&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-0.827&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-0.876&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-0.831&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>(0.042)</td>
<td>(0.044)</td>
<td>(0.038)</td>
<td>(0.051)</td>
<td>(0.046)</td>
</tr>
<tr>
<td>Ln Distance X Border</td>
<td>-0.194&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td>-0.142&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.073)</td>
<td></td>
<td>(0.096)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ln Distance X Importer Border</td>
<td></td>
<td></td>
<td></td>
<td>-0.127&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.064)</td>
<td></td>
</tr>
<tr>
<td>Ln Distance X Exporter Border</td>
<td></td>
<td></td>
<td></td>
<td>-0.245&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.060)</td>
<td></td>
</tr>
<tr>
<td>Border (dummy)</td>
<td>1.530&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.052</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.56)</td>
<td>(0.72)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exporter border (dummy)</td>
<td></td>
<td></td>
<td></td>
<td>-0.189&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.097)</td>
<td></td>
</tr>
<tr>
<td>Importer border (dummy)</td>
<td></td>
<td></td>
<td></td>
<td>0.0164</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.11)</td>
<td></td>
</tr>
<tr>
<td>Ln GDP Exporter</td>
<td>1.111&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.069&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.053&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.515&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.150&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>(0.053)</td>
<td>(0.054)</td>
<td>(0.024)</td>
<td>(0.22)</td>
<td>(0.034)</td>
</tr>
<tr>
<td>Ln GDP Importer</td>
<td>1.238&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.199&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.063&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.180&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.073&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>(0.051)</td>
<td>(0.053)</td>
<td>(0.023)</td>
<td>(0.036)</td>
<td>(0.21)</td>
</tr>
<tr>
<td>Density Exporter</td>
<td>-0.725&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-0.579&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-0.840&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-1.87&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-0.881&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>(0.28)</td>
<td>(0.28)</td>
<td>(0.23)</td>
<td>(0.66)</td>
<td>(0.31)</td>
</tr>
<tr>
<td>Density Importer</td>
<td>-1.14&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-1.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-1.49&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-0.989&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-3.52&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>(0.26)</td>
<td>(0.26)</td>
<td>(0.25)</td>
<td>(0.31)</td>
<td>(0.62)</td>
</tr>
<tr>
<td>Contiguity</td>
<td>0.499&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.505&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.606&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.517&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.531&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>(0.089)</td>
<td>(0.089)</td>
<td>(0.098)</td>
<td>(0.090)</td>
<td>(0.088)</td>
</tr>
<tr>
<td>Exporter dummies</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Importer dummies</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>N</td>
<td>832</td>
<td>832</td>
<td>832</td>
<td>832</td>
<td>832</td>
</tr>
<tr>
<td>RMSE</td>
<td>0.453</td>
<td>0.450</td>
<td>0.573</td>
<td>0.452</td>
<td>0.447</td>
</tr>
<tr>
<td>R²</td>
<td>93.5</td>
<td>93.6</td>
<td>89.7</td>
<td>93.6</td>
<td>93.7</td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses. <sup>a</sup>p < 0.01, <sup>b</sup>p < 0.05, <sup>c</sup>p < 0.1

include constants and exporter/importer fixed effects; not shown.

point s. Note that X (s) depends on the domestic and foreign distribution of infrastructure. If the government is free to spend B on whatever infrastructure distribution it prefers, and does not impose any additional tax, it will find it optimal to make fees dependent on the distance to the border, with higher fees the closer the border. Moreover, it will concentrate its spending as before in the central regions of the jurisdiction. The reason for this result is identical to the one discussed above: The government cares only about home welfare, thus taxing foreigners and transferring the receipts to home citizens is a welcome option.
If governments are not allowed to spend toll income on places other than those were
the income has been generated, there will now be a direct link between infrastructure
investment and transit volume, \( f(s) X(s) / q(s) = i(s) \). Governments will then set \( f(s) \)
such that native welfare is maximized. By imposing high fees in border regions, govern-
ments tax foreign consumers more strongly than domestic ones; however, the implied high
investment volumes are of little value for domestic consumers. By imposing high fees in
the center, governments affect domestic consumers, but also achieve high utility for them.
The implied distribution of infrastructure need not exhibit excessive spatial variation, but
it still can; the exact outcome depending on underlying model parameters.

There are a number of institutional arrangements that involve the private sector into
the construction and maintenance of transport infrastructure projects. Governments
could sell exploitation licenses to private firms who construct roads and set fee struc-
tures \( f(s) \). While this is a choice of many governments, the economic modeling poses
a number of problems, since one would have to decide whether the licenses are sold to
a single provider, to a consortium, or to local monopolists, and whether those firms can
commit to certain fee schedules and infrastructure investments when making their bids.

**Supranational entities.** Since decentralized transport infrastructure decisions gen-
erate positive externalities leading to a global underprovision and excessive spatial vari-
ation of infrastructure investment, there is a case for a supranational entity, such as the
European Union (EU), to intervene. Indeed, the EU is involved in a large project, the
Trans-European-Networks (TEN), that strives to coordinate and cofinance national in-
frastructure provision efforts. Member states have committed themselves to construct a
number of road and rail links that link European regions. The EU, in turn, cofinances
these projects. The degree of cofinancing is higher in peripheral regions than in central
ones. Is this policy able to internalize the externalities highlighted in the present paper?

In principle, the answer is yes. In order to achieve the first-best infrastructure distri-
bution, the EU should be allowed to tax citizens (or member state governments on their
behalf) and subsidize the price of infrastructure. For example if \( q'(s) = 1 \) for all \( s \), so
that the efficient infrastructure schedule should exhibit no spatial variation, the EU could
allow subsidize \( q(s) \) such that the effective price of infrastructure projects paid by do-
metric governments declines as we move closer to the border. The optimal rate of decline
should be related to the rate at which the the share of domestic beneficiaries falls, so that
the growth rates of the stock of infrastructure investment is zero across space; see, e.g.,
equation (16).

The problem with the above subsidization principle is that it does not ensure that the
overall quantity of infrastructure provision is efficient. To the extent that the domestic
planner overinvests in the neighborhood of the median address $\bar{x}$, a policy geared towards
a uniform spatial distribution of infrastructure leads to overinvestment.

**Internal labor mobility.** Instead of allowing goods prices to adjust to demand con-
ditions so that an endogenous distribution $p(s)$ emerges but leave the distribution $m(s)$
uniform, one could also let $m(s)$ adjust endogenously so that indirect utilities are equal-
ized across space. The governments would nevertheless propose uneven infrastructure
investment schedules, since they still fail to take into account the positive externality that
they exert on consumers in the rest of the world.

### 7.2 Conclusions

This paper develops a model where consumers demand goods from the entire world, but
the world is fragmented into jurisdictions which set infrastructure investment schedules
in a non-cooperative way. Governments caring only for their own welfare constituency
will ignore the effects that their decisions have on foreign consumers; this basic external-
ity leads to global underinvestment. The externality is stronger the more foreign-bound
transit flows through an address, and the size of such transit is larger the closer na-
tional borders are to that address. Hence, infrastructure underinvestment is stronger in
peripheral regions of jurisdictions rather than in central ones.

The local lack of infrastructure investment makes imports from other countries more
expensive than imports from other regions from the same country, even if geographical dis-
tance or incomes of trading partners are the same. Our infrastructure story may therefore
contribute towards unpacking trade costs and explaining the border puzzle highlighted

The paper also presents some tentative empirical support for the theoretical results,
drawing on trade data for US states. It turns out that trade relations that involve at least
one border region feature higher distance elasticities. Hence, transportation costs seem
higher for the same distance when a border is crossed.
References


A Various proofs

A.1 Proof of Lemma 1

General remark. The restriction \( \delta > 1 \) can be relaxed to \( \delta \geq 1 \) if \( T(x, z) \) is rewritten as
\[
T(x, z) = \exp \left\{ \frac{1}{\delta - 1} \int_x^z i(s)^{1-\delta} \, ds \right\}.
\]
In this case, one gets \( T(x, z) \rightarrow \exp \left[ \int_x^z \ln i(s) \, ds \right] \) as \( \delta \rightarrow 1 \). Otherwise, the properties of \( T(x, z) \) are unchanged. However, all equilibrium allocations of \( i(s) \) have to be checked for satisfying the restriction \( T(x, z) \geq 1 \). Cases where \( 0 < \delta < 1 \) must be ruled out as they increase the value

Property (iii). The behavior of \( T(x, z) \) with respect to geographical distance can be checked by looking at the derivative of \( T(x, z) \) with respect to \( z \).

\[
T(x, z) = \exp \left\{ \frac{1}{\delta - 1} \int_x^z i(s)^{1-\delta} \, ds \right\}
\]
\[
T_z(x, z) = T(x, z) \frac{1}{\delta - 1} \left[ i(z)^{1-\delta} \right] > 0
\]
\[
T_{zz}(x, z) = T(x, z) \left\{ \frac{1}{\delta - 1} \left[ i(z)^{1-\delta} \right] \right\}^2 - T(x, z) i(z)^{-\delta} i'(z) \geq 0 \]
\[
\iff \left( \frac{i(z)^{1-\delta}}{\delta - 1} \right)^2 \geq i'(z) i(z)^{-\delta}
\]

The LHS shows the effect of a marginal increase in distance on \( T_z(x, z) \) under the assumption that \( i(z + dz) = i(z) \). It reflects variation in trade costs due to an increase in distance, holding infrastructure constant. The RHS makes the opposite assumption and reports the change in \( T_z(x, z) \) due to the difference in infrastructure investment between \( z \) and \( z + dz \), holding the sheer costs of distance constant. \( T(x, z) \) is strictly convex (as in Krugman), if the LHS dominates.

Property (iv). We compute the elasticity of substitution between investment at two different addresses \( s', s'' \in [x, z] \) as follows
\[
\frac{\frac{d \ln [i(s')/i(s'')]}{d \ln i}}{\frac{\partial T/\partial i(s')}{\partial T/\partial i(s'')}} = \frac{d \ln [i(s')/i(s'')]}{d \delta \ln [i(s')/i(s'')]} = \frac{1}{\delta}
\]

Property (v). For \( i(s), s \in [x, z] \), we have
\[
T(x, z) = \exp \left\{ \frac{1}{\delta - 1} \int_x^z i(s)^{1-\delta} \, ds \right\}
\]
\[
\frac{\partial T(x, z)}{\partial i(s)} = -T(x, z) i(s)^{-\delta} < 0,
\]
\[
\frac{\partial^2 T(x, z)}{\partial i(s)^2} = T(x, z) \left[ i(s)^{-2\delta} + \delta i(s)^{-\delta-1} \right] > 0
\]

Property (vi). The Lagrangian to the problem is given by
\[
\Lambda (\{i(s)\}, \lambda) = \exp \left\{ \frac{1}{\delta - 1} \int_x^z i(s)^{1-\delta} \, ds \right\} + \lambda \left[ q \int_x^z i(s) \, ds - B \right]
\]
The first order conditions for investment at any two addresses \(k, l \in [x, z]\) imply
\[
i (k) = i (l).
\]

### A.2 Proof of Proposition 1

The first order condition for agent \(x\) has the form
\[
\frac{1 - \sigma}{\alpha} \frac{\partial t}{\partial i (s)} F (x) + (1 - t) \frac{\partial F (x)}{\partial i (s)} = 0
\]
where
\[
\frac{\partial t}{\partial i (s)} = q (s) / b \text{ for all } s
\]
from the government budget constraint, and
\[
\frac{\partial F (x)}{\partial i (s)} = \begin{cases}
  i (s)^{-\delta} (\sigma - 1) \int_{z \in L(s)} T (z, x)^{1-\sigma} d z & \text{if } s \in L (x) \\
  i (s)^{-\delta} (\sigma - 1) \int_{z \in R (s)} T (x, z)^{1-\sigma} d z & \text{if } s \in R (x)
\end{cases}
\]
The limits of integration in the last expression follow from the fact that when \(s \in L (x)\), only deliveries of goods from locations \(z \in L (s)\) are affected by investment at \(s\), the remaining deliveries are not affected; similarly for \(s \in R (x)\).

Hence, the first order condition is
\[
i (s)^{\delta} = \begin{cases}
  (1 - \alpha) b [(1 - t) / q (s)] \left[ F^L (s) (x) / F (x) \right] & \text{if } s \in L (x) \\
  (1 - \alpha) b [(1 - t) / q (s)] \left[ F^R (s) (x) / F (x) \right] & \text{if } s \in R (x)
\end{cases}
\]
where we have used the notation introduced in (14).

### A.3 Proof of Proposition 2

**Proportional growth rate.** Note that in \(t\) and \(F (x)\) the dependence on \(s\) has been integrated out. Then, differentiating the result in Proposition 1 for the case \(s \in R (x)\) with respect to \(s\), we obtain
\[
i' (s) = - \frac{1}{\delta} \left[ \frac{(1 - \alpha) b (1 - t)}{F (x)} \right] ^{\frac{1}{2}} \left[ \frac{F^R (s) (x)}{F (x)} \right] ^{\frac{1-\delta}{\delta}} \left[ T (x, s)^{1-\sigma} q (s) + q' (s) \int_{s}^{1} T (x, z)^{1-\sigma} d z \right] / q (s)^2
\]
which can be straightforwardly used to compute (16) in the text. Similarly for the case \(s \in L (x)\).

**Strict concavity of \(i^x (s)\).** The growth rate of infrastructure investment at \(s \in R (x)\) desired by agent \(x\) is
\[
g^x (s) = - \frac{1}{\delta} \int_{s}^{1} T (x, z)^{1-\sigma} d z.
\]
We have
\[
\frac{\partial T (x, s)}{\partial s} = T (x, s) \frac{i (s)^{1-\delta}}{\delta - 1} > 0.
\]
The first order condition to problem (20) is

\[ A.4 \text{ Proof of Proposition 3} \]

away from \( \bar{s} \). In other words,

\[ \frac{\partial t}{\partial x} = -T(x, s) \frac{i(s)^{1-\delta}}{\delta - 1} < 0 \]

so the growth rate of \( i(s) \) is negative and decreasing in \( s \). It follows that \( i(s) \) is strictly concave in \( s \).

**Shape of \( i^x(s) \) for different \( x \).** Next, we may compute

\[ \frac{\partial T(x, s)}{\partial x} = -T(x, s) \frac{i(s)^{1-\delta}}{\delta - 1} < 0 \]

and

\[ \frac{\partial g^x(s)}{\partial x} = -\frac{1 - \sigma}{\delta} T(x, s)^{-\sigma} \left[ \frac{\partial T(x, s)}{\partial x} \int_s^1 T(x, z)^{1-\sigma} dz \right. \]

\[ \left. + T(x, s) \int_s^1 T(x, z)^{-\sigma} \frac{\partial T(x, z)}{\partial x} dz \right] > 0 \] (28)

It follows that the desired growth rate \( g^x(s) \) is less negative for a given \( s \) for a household with a lower distance to the point of investment \( s \).

**Comparison of preferred tax rates \( t^x \).** We may use figure 4 to show that the tax rates preferred by an agent at address \( x \) is larger than the one preferred by the median agent, i.e., \( t^x > t^\bar{x}, x \neq \bar{x} \) and \( \partial t^x / \partial |x - \bar{x}| \). First, note that the \( t^\bar{x} \) is given by the area below the curve \( i^x(s) \), which is a continuous function of \( s \). Now consider the preferred investment schedule of an agent residing at \( \bar{x} + dx \). We still have \( i^\bar{x} + dx (0) = i^\bar{x} + dx (1) = 0 \), so that differences in the slopes \( g^x(s) \) and \( g^\bar{x} + dx (s) \) suffice to make claims about \( t^\bar{x} (s) \) and \( t^\bar{x} + dx (s) \). In our figure, \( dx > 0 \). Equation (28) shows that for points lying to the right of \( \bar{x} + dx \), we have \( g^\bar{x} + dx (s) > g^\bar{x} (s) \) while for points to the left, the contrary holds. Now, holding \( x \) constant, we would have

\[ \int_0^{\bar{x} + dx} i^\bar{x}(s) ds + \int_0^{\bar{x} + dx} i^\bar{x}(s) ds = \int_{\bar{x} + dx}^{\bar{x} + dx} i^\bar{x} + dx(s) ds + \int_{\bar{x} + dx}^{\bar{x} + dx} i^\bar{x} + dx(s) ds. \]

Now, since \( i^\bar{x} (s) < i^\bar{x} + dx (s) \) for all \( s < \bar{x} + dx \) and \( i^\bar{x} (s) > i^\bar{x} + dx (s) \) for all \( s > \bar{x} + dx \) it holds that

\[ t^\bar{x} + dx = \int_{\bar{x} + dx}^{\bar{x} + dx} i^\bar{x} + dx(s) ds + \int_{\bar{x} + dx}^{\bar{x} + dx} i^\bar{x} + dx(s) ds > t^\bar{x}. \]

In other words, \( \partial t^\bar{x} / \partial x > 0 \). This holds a fortiori for larger than infinitesimal deviations of \( x \) away from \( \bar{x} \).

**A.4 Proof of Proposition 3**

The first order condition to problem (20) is

\[ -\frac{\sigma - 1}{\alpha} q(s) b \int_0^1 F(x) dx + \frac{\partial}{\partial s} \int_0^1 F(x) dx = 0. \] (29)

where the relevant component of gross welfare affected by investment at \( s \) is

\[ \int_s^1 \int_0^1 T(z, x)^{1-\sigma} dz dx + \int_0^1 \int_s^1 T(x, z)^{1-\sigma} dz dx. \] (30)
Moreover, the marginal effect of a change of \( i(s) \) on \( T(x,z)^{1-\sigma} \) is

\[
\frac{\partial}{\partial i(s)} T(x,z)^{1-\sigma} = (\sigma - 1) T(x,z)^{1-\sigma} i(s)^{-\delta} \geq 0.
\]

We may now write (30) the marginal effect of \( di(s) \) on social welfare as

\[
\frac{\partial}{\partial i(s)} \int_0^1 F(x) \, dx = (\sigma - 1) i(s)^{-\delta} \left[ \int_s^1 \int_0^x T(z,x)^{1-\sigma} \, dz \, dx + \int_0^s \int_x^1 T(x,z)^{1-\sigma} \, dz \, dx \right],
\]

which, inserted into the F.O.C. (29) delivers

\[
\frac{1}{\alpha} \frac{q(s)}{1-t} \frac{1}{b} \int_0^1 F(x) \, dx = i(s)^{-\delta} \left[ \int_s^1 \int_0^x T(z,x)^{1-\sigma} \, dz \, dx + \int_0^s \int_x^1 T(x,z)^{1-\sigma} \, dz \, dx \right],
\]

which can be rewritten, using the definitions of \( \phi^R(s) \) and \( \phi^L(s) \) as in Proposition 3 in the text.

\[
i(s) = [\alpha (1-t) b]^{1/\delta} \left[ \frac{\phi^L(s) + \phi^R(s)}{q(s)} \right]^{1/\delta},
\]

where

\[
\phi^L(s) = \frac{\int_s^x \int_0^1 T(z,x)^{1-\sigma} \, dz \, dx}{\int_0^1 F(x) \, dx} \quad \text{and} \quad \phi^R(s) = \frac{\int_0^s \int_1^x T(x,z)^{1-\sigma} \, dz \, dx}{\int_0^1 F(x) \, dx}
\]

A.5 Proof of Proposition 4

Differentiating the first order conditions in Proposition 3 with respect to \( s \)

\[
\frac{i'(s)}{i(s)} = \frac{1}{\delta} \left[ \frac{\alpha}{\phi^L(s) + \phi^R(s)} \left( \frac{\phi^L(s)}{q(s)} + \frac{\phi^R(s)}{q(s)} \right) - \frac{q'(s)}{q(s)} \right].
\]
The derivatives of \( \phi_L(s) \) and \( \phi_R(s) \) are, respectively
\[
\phi_L^L(s) = \frac{1 - \sigma}{\int_0^1 F(x) dx} \left[ \int_s^1 T(s,x)^{-\sigma} \frac{\partial T(s,x)}{\partial s} dx + \int_0^s T(z,s)^{-\sigma} \frac{\partial T(z,s)}{\partial s} dz \right],
\]
\[
\phi_R^R(s) = \frac{1 - \sigma}{\int_0^1 F(x) dx} \left[ \int_s^1 T(x,s)^{-\sigma} \frac{\partial T(x,s)}{\partial s} dx + \int_0^s T(s,z)^{-\sigma} \frac{\partial T(s,z)}{\partial s} dz \right].
\]
Substituting out the partial derivatives, \( \partial T(z,s)/\partial s = T(z,s) \iota(s) \), \( \partial T(s,z)/\partial s = -T(z,s) \iota(s) \), \( \partial T(s,x)/\partial s = -T(s,x) \iota(s) \) and \( \partial T(x,s)/\partial s = T(x,s) \iota(s) \), where \( \iota(s) \equiv i(s)^{1-\delta}/(\delta - 1) \), we have
\[
\phi_L^L(s) = \frac{1 - \sigma}{\int_0^1 F(x) dx} \iota(s) \left[ -\int_s^1 T(s,x)^{-\sigma} dx + \int_0^s T(z,s)^{-\sigma} dz \right],
\]
\[
\phi_R^R(s) = \frac{1 - \sigma}{\int_0^1 F(x) dx} \iota(s) \left[ \int_0^s T(x,s)^{-\sigma} dx - \int_0^1 T(s,z)^{-\sigma} dz \right].
\]
It follows that
\[
\frac{i'(s)}{i(s)} = \frac{1}{\delta} \left[ (1 - \sigma) \iota(s) \left[ -\int_s^1 T(s,x)^{-\sigma} dx + \int_0^s T(z,s)^{-\sigma} dz + \int_0^s T(x,s)^{-\sigma} dx - \int_0^1 T(s,z)^{-\sigma} dz \right] \right] - \frac{q'(s)}{q(s)}.
\]
Exploiting the symmetry of trade costs, i.e., \( T(a,b) = T(b,a) \), defining \( \Delta(s) \equiv \int_s^1 T(s,x)^{-\sigma} dx - \int_0^s T(x,s)^{-\sigma} dx \), the expression simplifies to
\[
\frac{i'(s)}{i(s)} = \frac{1}{\delta} \left[ \sigma - 1 \iota(s)^{1-\delta} \frac{\Delta(s)}{\int_s^1 \int_0^s T(z,x)^{-\sigma} dz dx} - \frac{q'(s)}{q(s)} \right],
\]
which is equation (21) used in the text.

### A.6 Proof or Proposition 5

**First order condition.** Now, agent \( x \) decides on \( i(s) \), where \( s \in [0,1] \), but consumes goods from \( s \in [0,2] \). The given foreign infrastructure distribution is \( i^*(s) \), where \( s \in [1,2] \). The F.O.C. of agent \( x \) remains essentially the same as before, with the only difference that the sets \( L(s) \), \( R(s) \) contain foreign addresses as well. Hence,
\[
i(s)^{\delta} = \begin{cases} 
\alpha b [(1-t)/q(s)] \int F_L(x)/F(x) & \text{if } s \in L(x) \\
\alpha b [(1-t)/q(s)] \int F_R(x)/F(x) & \text{if } s \in R(x) 
\end{cases}
\]

For the case of \( s \in R(x) \), we have
\[
\phi^{sR}(x,s) = \frac{\int_s^1 T(x,z)^{-\sigma} dz + K}{\int_0^1 T(x,z)^{-\sigma} dz + K}
\]
where \( K = \int_0^2 T(x,z)^{-\sigma} dz \). \( \phi^{sR}(x,s) \) under autarky is obtained by setting \( K = 0 \). Regardless of the exact distribution of \( i^*(s) \), we can note that \( \phi^{sR}(x,s) = \phi^{sR}(x,s) \zeta + (1 - \zeta) \), where \( \zeta \equiv \int_0^1 T(x,z)^{-\sigma} dz / \left[ \int_0^1 T(x,z)^{-\sigma} dz + K \right] \). Hence, \( \phi^{sR}(x,s) \geq \phi^R(x,s) \).
Growth rate of $i^x(s)$ Also the growth rate of $i^x(s)$ is derived exactly as before.

$$g^H_x(s) = -\frac{1}{\delta} \left[ \frac{T(x,s)^{1-\sigma}}{F^R(s)(x)} + \frac{q'(s)}{q(s)} \right].$$

For the case where $q'(s)/q(s)$ is finite, we now find that $|g^x(1)|$ is a finite number (possibly zero), too, and no longer infinite as under autarky.

A.7 Proof of Proposition 6

We focus on symmetric situations only. In that case, infrastructure investments in Home and Foreign, will be mirrored at about the border point $s = 1$, i.e. $i^H(s) = i^F(2-s)$. We define $H$ as the set of points $[0,1]$ and $F$ as the set of points $[1,2]$

Indirect utility of an agent $x \in H$ is

$$V^H(x) = \int_0^x T(z,x)^{1-\sigma} dz + \int_x^2 T(x,z)^{1-\sigma} dz$$

while that of an agent $x' \in F$ is

$$V^F(x') = \int_0^{x'} T(z,x')^{1-\sigma} dz + \int_{x'}^2 T(x',z)^{1-\sigma} dz$$

The crucial thing now is that $L(x)$ contains addresses only from $H$, while $R(x)$ contains addresses from $F$ as well. Similarly, $L(x')$ contains points from $H$, while $R(x')$ does not. The sets $R(x), L(x), R(x'), L(x')$ define the economic space, while $H$ and $F$ define the political space of the model.

B Data Appendix to Table 1

Construction of variables.

(a) Miren Lafourcade has kindly provided access to generalized trade cost data for France départements for the year of 1993. Those data are constructed as the (more disaggregated, but unfortunately confidential) data that Combes et Lafourcade (2005) describe. The data contains trade costs département by département. One can recover total variable transport costs by subtracting the costs of loading and unloading the truck of FF 60. To obtain a measure of transit costs, we average total variable transport costs per kilometer between neighboring départements, using the neighbours’ area as weights.

(b) Geographical difficulty is the measured by the difference between the points of highest and lowest altitude above sea level in a département.

(c) Trade cost weighted distance to Paris is the generalized trade cost index (including fixed costs, as reported by Combes and Lafourcade, 2005) for transportation from or to Paris to or from the respective département.
Table 5: Summary statistics for Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ln variable transport costs(^{(a)})</td>
<td>1.57</td>
<td>0.11</td>
<td>1.18</td>
<td>1.73</td>
</tr>
<tr>
<td>Ln geographical difficulty(^{(b)})</td>
<td>-0.51</td>
<td>1.02</td>
<td>-2.35</td>
<td>1.52</td>
</tr>
<tr>
<td>Ln population</td>
<td>13.03</td>
<td>0.70</td>
<td>11.20</td>
<td>14.74</td>
</tr>
<tr>
<td>Ln area in square km</td>
<td>8.53</td>
<td>0.70</td>
<td>5.16</td>
<td>9.23</td>
</tr>
<tr>
<td><strong>Remoteness measures</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ln distance to Paris</td>
<td>0.33</td>
<td>0.17</td>
<td>0.01</td>
<td>0.66</td>
</tr>
<tr>
<td>Ln trade costs weighted distance to Paris(^{(c)})</td>
<td>5.25</td>
<td>0.84</td>
<td>2.48</td>
<td>6.24</td>
</tr>
<tr>
<td>Ln distance to rest of France(^{(d)})</td>
<td>7.84</td>
<td>0.15</td>
<td>7.58</td>
<td>8.27</td>
</tr>
<tr>
<td>Ln trade costs weighted distance to rest of France(^{(e)})</td>
<td>0.42</td>
<td>0.19</td>
<td>0.08</td>
<td>0.90</td>
</tr>
</tbody>
</table>

\(^{(d)}\) Distance to rest of France is computed as the average unweighted distance of some département to all the other départements.

\(^{(e)}\) Repeats the exercise conducted for \(^{(d)}\), but uses generalized trade costs instead of distance (as reported by Combes and Lafourcade, 2005).